Spin dynamics and magnon linewidth in the long wavelength limit in diluted systems

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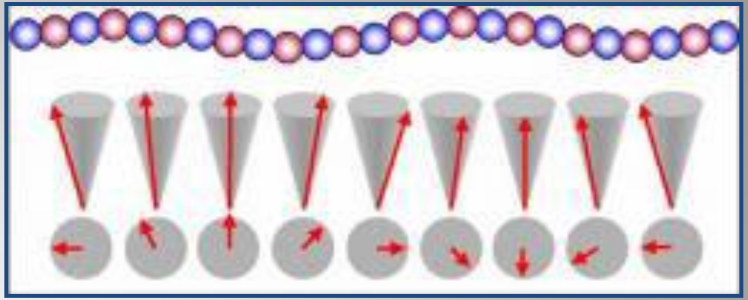
MARIE CURIE ACTIONS

- **Spin waves:** oscillations in the relative orientations of spins on a lattice with continuous symmetry
- Quantized collective excitations : **Magnons**



Spin wave intrinsic linewidth : Measures the broadening of the magnetic excitations

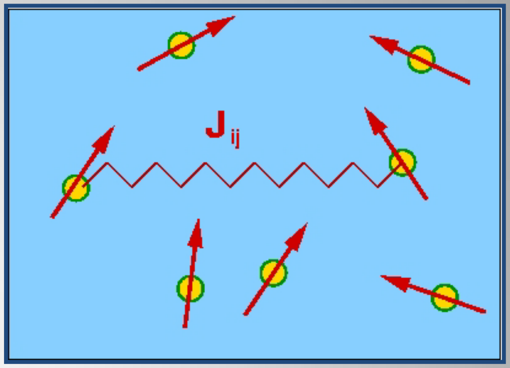
Wave vector dependence of the linewidth in disordered ferromagnets, till now…

- *V. A. Singh and L. M. Roth*, J. Appl. Phys. (1978) - q^5
- *T. Kaneyoshi*, J. Phys. Soc. Jpn. (1978) - q^7
- *Y. Ishikawa et. al.,* J. Phys. Soc. Jpn. (1981) - q^2
- *H. Mano*, J. Phys. Soc. Jpn. (1982) - q^5
- *A. Christou and R. B. Stinchcombe*, J. Phys. C:Solid State Phys. (1986) - q^{d+2}

Theoretical approach and model

The Heisenberg model and the Self-Consistent Local Random Phase Approximation (SC-LRPA)

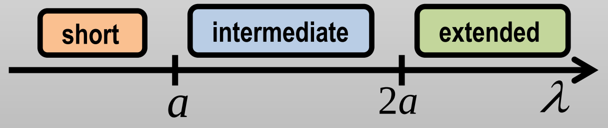
$$H_{Heis} = -\sum_{ij} J_{ij}\, p_i\, p_j\, S_i . S_j$$



- N_{imp} localized spins randomly distributed on a lattice of N sites (concentration $x = N_{imp} / N$)
- p_i = 1, if the site is occupied otherwise 0
- S_i's here are classical spins (can be quantum too)

Exchange interactions

$$J_{ij} = J_0 \exp(-|r_{ij}| / \lambda)$$

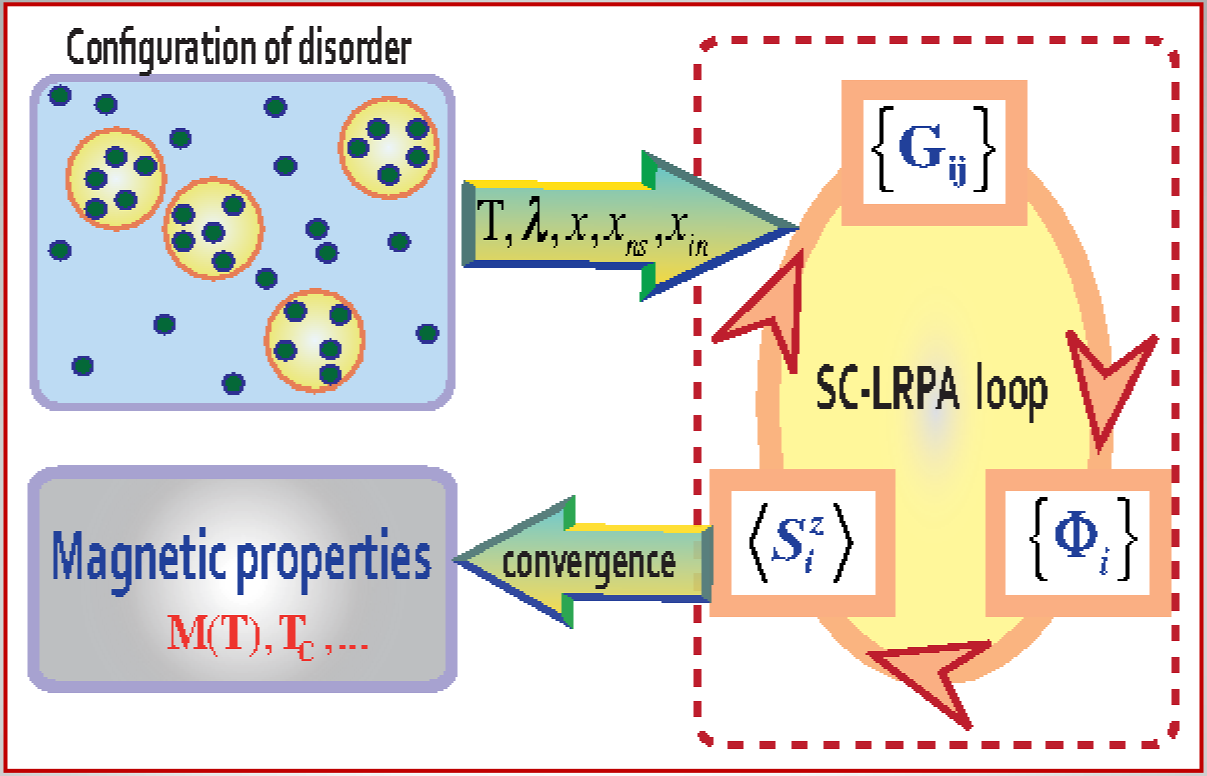


SC-LRPA: A finite temperature Green's functions based approach, allows to calculate the magnetic properties of diluted/disordered systems

$$G_{ij}(\omega) = -i\int_0^{\infty} \langle [S_i^+(t), S_j^-(0)] \rangle e^{i\omega t}\, dt$$

G. Bouzerar et. al. EPL 2005; PRB 2005
K. Sato et. al. Rev. Mod. Phys. 2010

Schematic of the SC-LRPA method



$$\langle S_i^z \rangle = \frac{(S-\Phi_i)(1+\Phi_i)^{2S+1} + (1+S+\Phi_i)\Phi_i^{2S+1}}{(1+\Phi_i)^{2S+1} - \Phi_i^{2S+1}}$$

⟹ **Local magnetization from Callen-like expression**

$$\Phi_i = -\frac{1}{2\pi\langle S_i^z \rangle}\int_{-\infty}^{+\infty} \frac{\Im G_{ii}(\omega)}{exp(\omega/kT)-1} d\omega$$

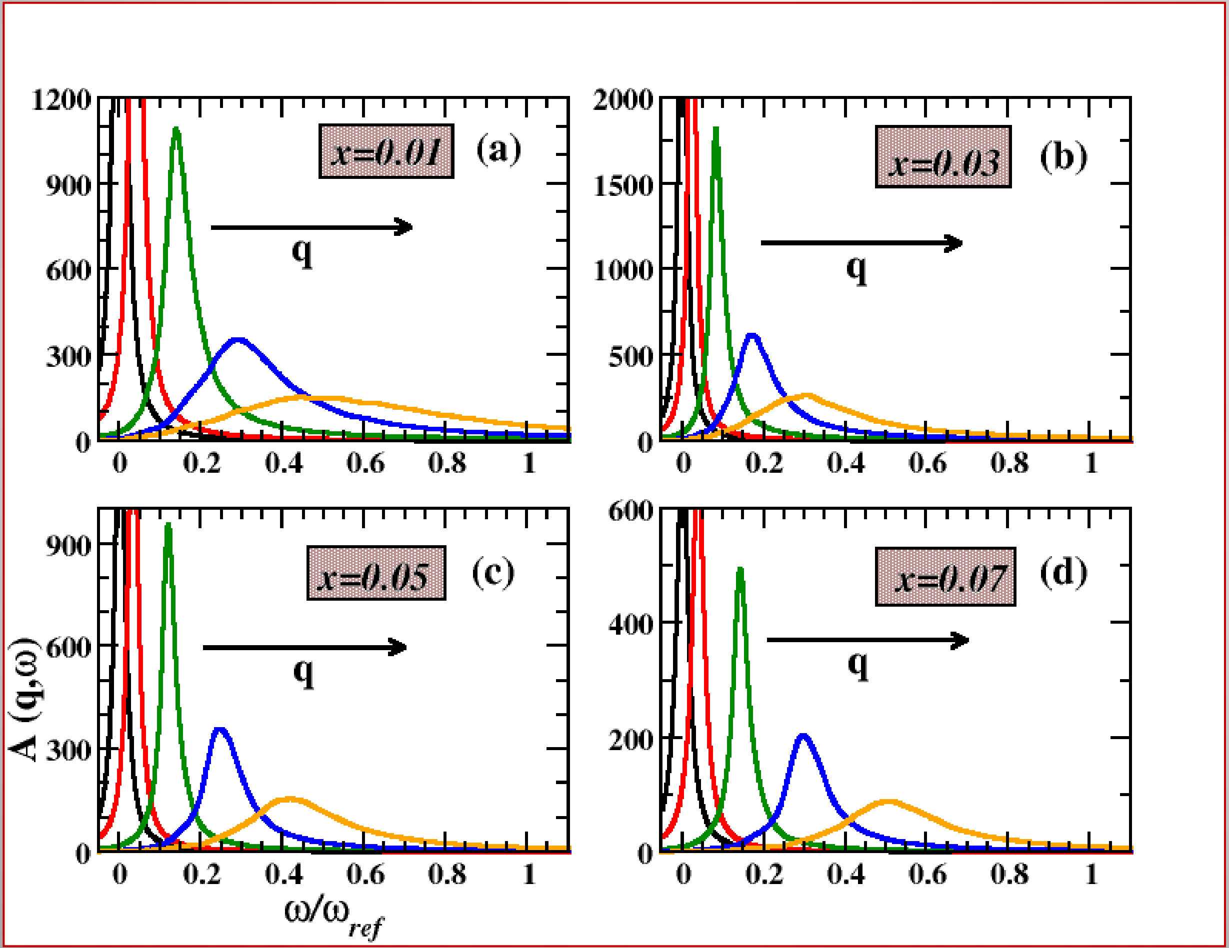
⟹ **Local effective magnon occupation number**

Dynamical Spectral Function

$$A(\vec{q},\omega) = \left\langle \sum_{\alpha} A_{\alpha}^{c}(\vec{q})\,\delta(\omega - \omega_{\alpha}^{c}) \right\rangle_{c}$$

$$A_{\alpha}^{c}(\vec{q}) = \frac{1}{N_{imp}} \sum_{ij} \lambda_j \langle i | \psi_{\alpha}^{R,c} \rangle \langle \psi_{\alpha}^{L,c} | j \rangle e^{i\vec{q}(\vec{r}_i - \vec{r}_j)}$$

$\lambda = a/2$



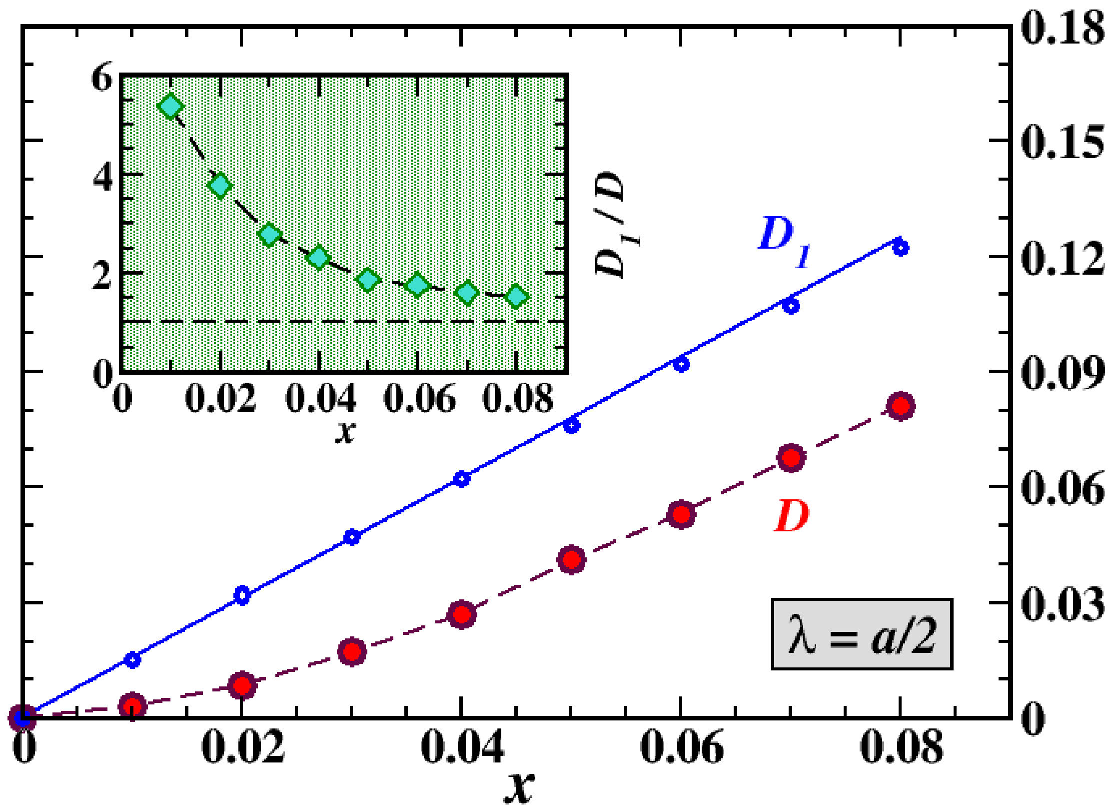
A(q,w) as a function of magnon energy in the (1 0 0) direction

Moments associated with the spectral function ⟹

$$m_n(\mathbf{q}) = \int_{-\infty}^{+\infty} \omega^n \bar{A}(\mathbf{q},\omega)\mathrm{d}\omega$$

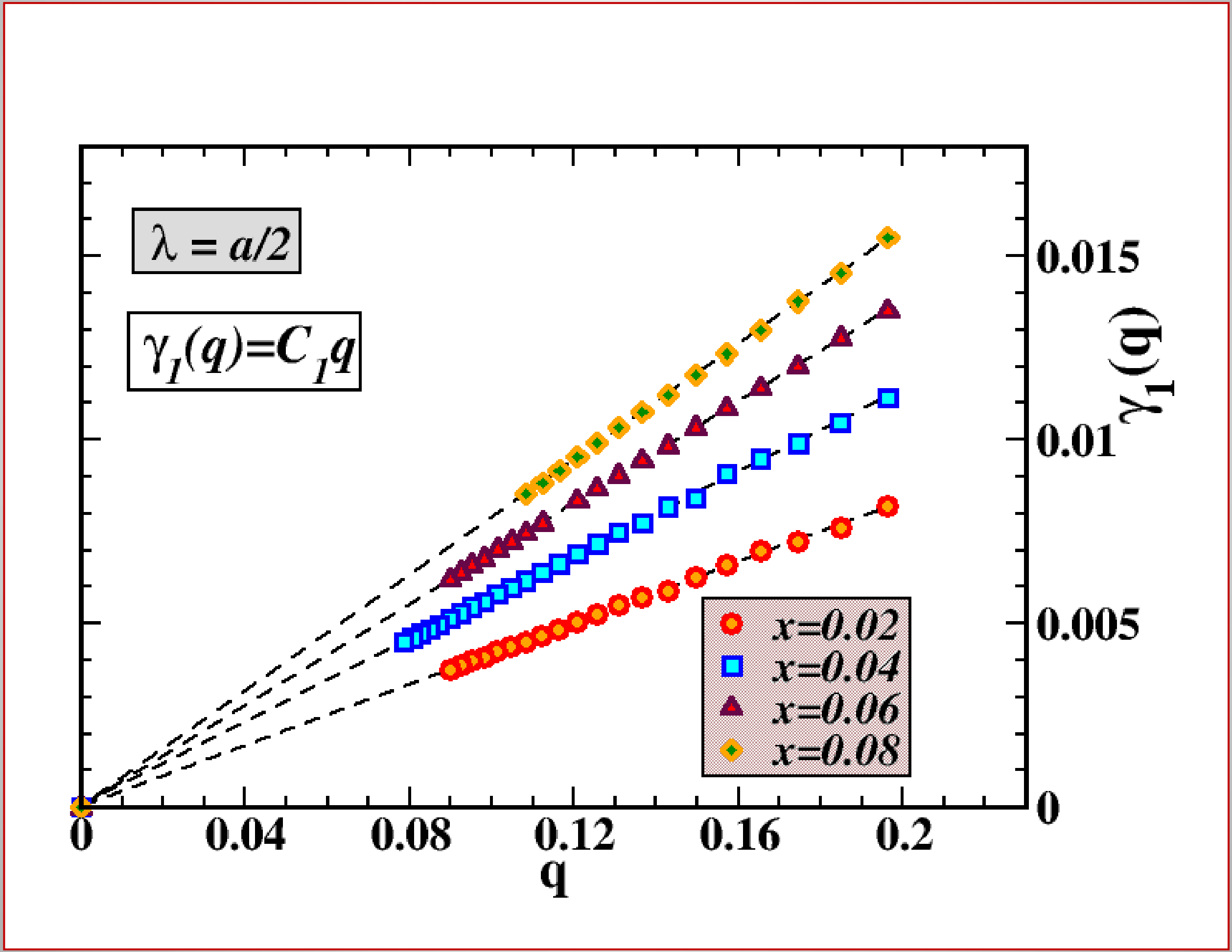
Spin-stiffness

$$q \to 0,\ \ \omega(q) = Dq^2$$
$$m_1(\mathbf{q}) \approx D_1 q^2$$



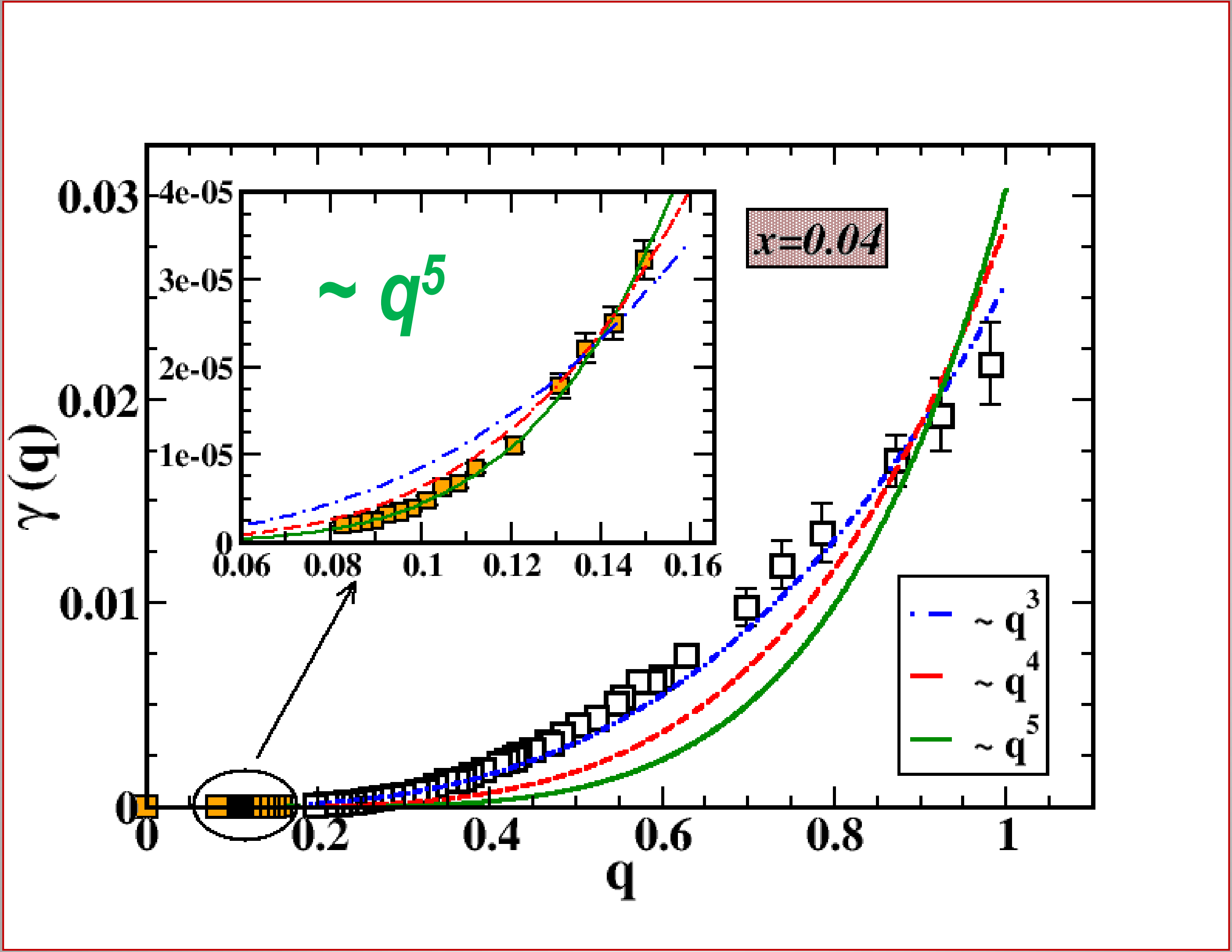
Effective linewidth from the second moment

$$\gamma(\mathbf{q}) = \sqrt{m_2(\mathbf{q}) - m_1^2(\breve{\mathbf{q}})}$$



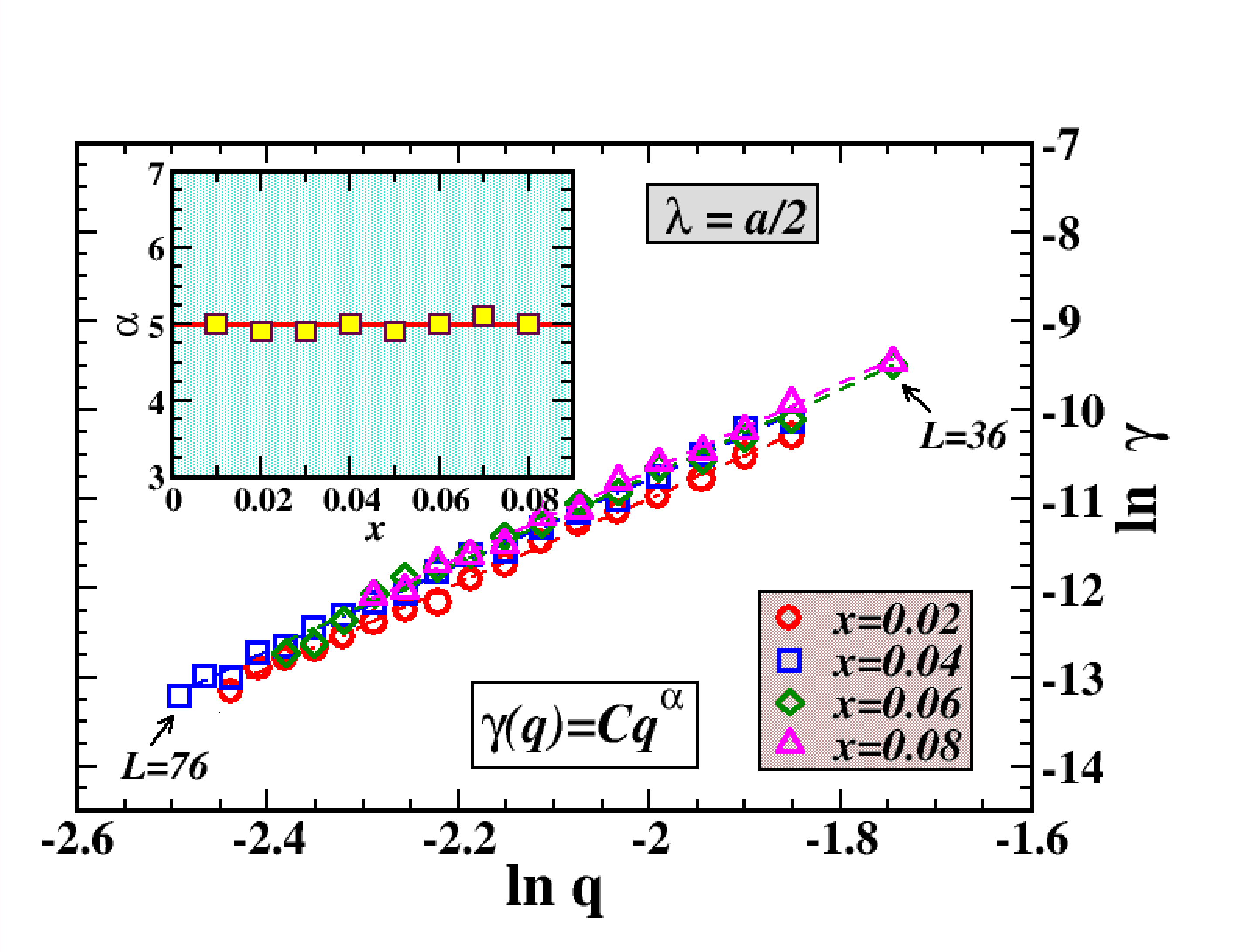
➢ *Second moment leads to incorrect linewidth behavior*

Real linewidth from the spectral function



✓ *In agreement with the theories of Singh, Mano and Christou*

Real linewidth for different dilutions



✓ q^5 behavior is persistent for a broad concentration range

Conclusion

- ✓ ***Disorder leads to strong asymmetry in the magnon excitations.***
- ✓ ***Moments are inappropriate to evaluate the real linewidth and spin stiffness.***
- ✓ ***Magnon linewidth varies as q^5, but only for sufficiently small q-values!***

Thank You…

More…

SC-LRPA Curie temperature

$$k_B T_C = \frac{2}{3N_{imp}} S(S+1) \sum_i \frac{1}{F_i}$$

$$\Longrightarrow$$

$$F_i = -\frac{1}{2\pi\lambda_i} \int_{-\infty}^{+\infty} \frac{\Im m\,(G_{ii}(E))}{E} dE,$$

$$\lambda_i = \lim_{T \to T_C} \frac{\langle S_i^z \rangle}{m} \quad \left(m = \frac{1}{N_{imp}} \sum_{i=1}^{N_{imp}} \langle S_i^z \rangle \right)$$

- **Semi-analytical expression for the Curie temperature, generalization of the RPA to disordered ferromagnetic systems**
- ***F_i*'s contain all multiple scattering effects, and calculated self-consistently for each configuration of disorder**
- **Mermin-Wagner and Goldstone theorems fulfilled, unlike the mean-field approximation**

Mean field Curie temperature : $T_C^{VCA} = \frac{2}{3} S(S+1) x \sum_i n_i J_i$

G. Bouzerar et. al. EPL 2005; PRB 2005
K. Sato et. al. Rev. Mod. Phys. 2010

The SC-LRPA method

The exact equation of motion of $G_{ij}(\omega)$ in real space is

$$\omega G_{ij} = 2\langle S_i^z \rangle \delta_{ij} + \langle\langle [S_i^+, \mathcal{H}]; S_j^- \rangle\rangle$$

$$[S_i^+, \mathcal{H}] = \sum_l J_{il}(S_i^z S_l^+ - S_l^z S_i^+)$$

$$\langle\langle S_i^+ S_l^z; S_j^- \rangle\rangle \longrightarrow \langle S_l^z \rangle \langle\langle S_i^+; S_j^- \rangle\rangle$$

$$(\omega - h_i^{eff}) G_{ij}(\omega) = 2\langle S_i^z \rangle \delta_{ij} - \langle S_i^z \rangle \sum_l J_{il} G_{lj}(\omega)$$

where $h_i^{eff} = \sum_l J_{il} \langle S_l^z \rangle$ is the local effective field at site i.

$$(\mathrm{H}_{eff})_{ij} = -\langle S_i^z \rangle J_{ij} + \delta_{ij} \sum_l \langle S_l^z \rangle J_{lj}$$